EXHIBIT N

Encyclopedia of Cognitive Science

User Interface Design

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Article definition

This article covers the basic issues that the field of cognitive science raises in the design and testing of new digital technologies for human use.

1. Introduction

The design of computer interfaces that are usable and easily learned by humans is a non-trivial problem for software developers. As information technologies mediate many of the activities we now perform routinely as part of our lives, the attention paid to the process of human-computer interaction is enormous. Since much of the process of interaction is cognitive in nature, involving perception, representation, problem solving, navigation, query-formulation and language processing, the theories and methods of cognitive science are viewed as directly relevant to such concerns. The result has been the emergence of an applied cognitive science for software design that is known as the field of Human-Computer Interaction or HCI.

2. Cognitive Science and design

Traditional cognitive science approaches to HCI and user interface design model the user as made up of three basic components: the psychomotor, perceptual, and cognitive sub-systems. Recent treatments of HCI have extended these to include the social system as a core part of the users make-up and placed greater emphasis on group dynamics and social context in examining what users do with technology. Any full treatment of user psychology must embrace all components, though it remains the case that cognitive issues dominate most research in HCI.

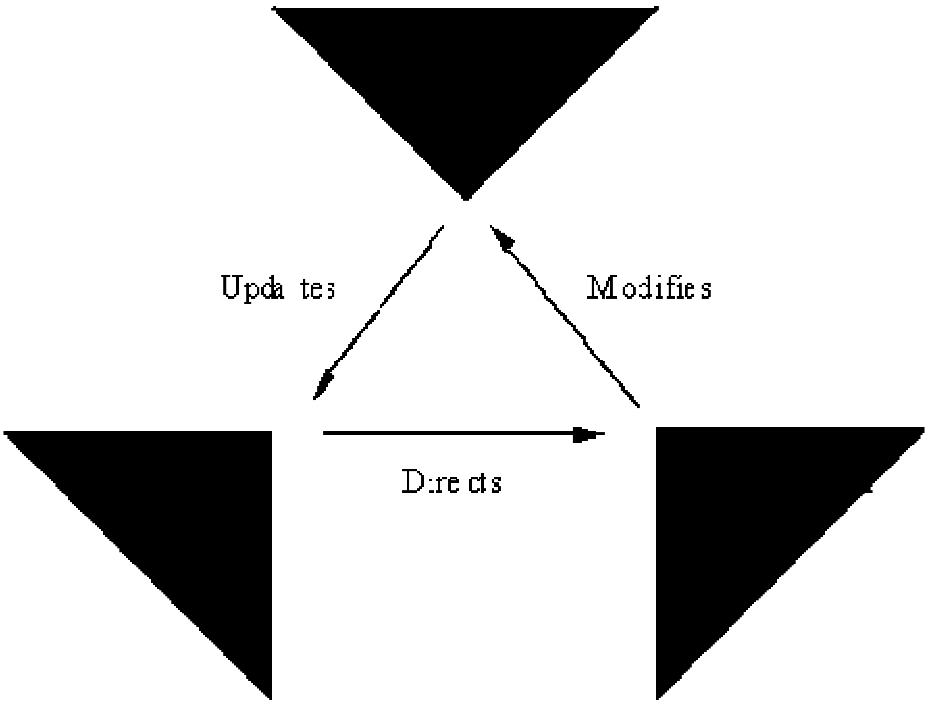
3. The Basics of Human-Computer Interaction:

The success of any computer application is dependent on it providing appropriate facilities for the task at hand in a manner that enables users to exploit them effectively.

Whereas the provision of facilities is an issue of functionality, the user interface is the means by which the functionality can be exploited, and here we are directly concerned with usability.

For interaction to proceed the human user must input a signal to the computer and perceive changes in the interface. Since much of current interaction involves physical input and visual perception of output, any basic interactive device must convey an input device and a screen. However, to determine the appropriate input the user must have some representation of a goal or intention of an outcome to attain, necessitating the employment of memory, both short (to handle current status information) and long-term (to enable the planning and interpretation of the interactive sequence).

Information undergoes transformation at each stage of progression from a perceived stimulus (e.g. a visual change in the interface) to a comprehended cue (e.g. a recognised sign) leading to an active response (e.g. push a mouse button). All of this happens repeatedly and rapidly as the human interacts with the system. This process can be simply envisioned using a variant of Neissers classic perceptual cycle model, whereby users engage in an ongoing cycle of information exchange involving exploration of a changing information environment (see Figure 1).



Insert Figure 1 Human Computer Interaction as iterative process

For example, any current interface provides a response to user input which signals to the user that their input has caused an action. Through direct manipulation, users can select and move objects on screen, open and close windows with a mouse click, or jump from place to place within documents via hyperlinks. In each case, the user must initiate an action and the interface must communicate its change of state through appropriate feedback to the user. Where feedback is vague, too rapid or non-existent, the user is likely to be confused as to the impact of their actions. Ideal feedback communicates to the user that the system status has altered in the intended manner and the user is closer to their goal as a result.

We can usefully understand HCI as a cognitive process by considering the human as possessing general knowledge structures (mental models, schemata, etc.) which organise the users task-oriented information exploration and use. This exploration, which may involve a host of psycho-physical actions such as keypresses, scrolling, link selection, command input etc., exposes the human to samples of the information space contained within the software, the perception of which must be interpreted and categorized, before

it in turn can influence the subsequent actions of the human and so forth in an iterative fashion.

This is a very general portrayal of user psychology. Its purpose is to convey the active nature of cognition and show how humans select information on the basis of expectation and prior experience and how the selected information can itself modify the knowledge structures within the human. Thus, while the general model holds true, in the interface design context, any one user is likely to have unique experiences and knowledge, which will influence their perception of, and interactions with a computer. Software designers are now very aware of the affect interface design has on the user experience of their products and as a result have sought guidance and input from cognitive scientists as to how best to design interfaces for usability and human acceptance.

The response from the cognitive community has been threefold: the derivation of design guidelines to aid designers; the formulation of theoretical models to predict user response in specific instances; and the development of design methods and evaluation techniques to improve the process of user-centered design.

4 Cognitive Design Guidelines: from psychophysics to semiotics

Since cognitive science has derived tremendous understanding of the mechanisms and processes underlying perception, memory, attention, categorisation, decision-making, comprehension and related processes and structures, it is reasonable to assume that such findings are very relevant to practical design issues. For interfaces, we need to consider if users will perceive actions and behaviors, how they will interpret them, what demands our designs place on their attention, what knowledge they will need to interpret and respond in a manner acceptable to the software. There have been many attempts to bridge the gap between scientific findings and software design, and a full set of guidelines drawn from studies of cognition could run to several volumes. As a result, much re-packaging of cognitive science has taken the form of general guidelines for designers to consider. The following represent a generic set that have gained broad acceptance by

most interface designers. In each case, the linkages with cognitive science should be readily apparent to the reader.

4.1 Screen readability and image quality

To perform most information tasks with a computer the user must be able to extract and process visual stimuli reliably and quickly. Early computer screens suffered from a variety of technological limitations that resulted in slower reading of electronic text than paper, or constrained the range of representations possible on screen. Current design guidance recommends the use of high resolution screens with strong image polarity (preferably dark on light) to enhance human perception. Standard design advice is to produce all interfaces so that they can work in monotone and to add color sparingly to guide visual processing, attract attention, and aid chunking. As we interact more and more with screens, both large and small, the importance of readability cannot be overlooked, and poor visual ergonomics can prevent otherwise sophisticated software from being fully exploited.

4.2 Manipulation and input devices

While the typical computer of today is a desktop model with a keyboard and a mouse, there are now many variants and alternatives such as PDA (Personal Digital Assistants) or laptop computers. These tools are designed for mobility, and use a stylus or trackpad as an input mechanism. Where once punched cards were the primary medium of interaction, the emergence of so-called Direct Manipulation interfaces has advanced the exploitation of natural mappings between pointing and positioning found in the real world with the control of objects in a digital environment. Immersive environments take this to the logical stage of creating a virtual world where users perform physical actions, much like the real world, to affect responses from the software.

Studies of input devices have revealed that a mouse is fairly optimal for most standard pointing and clicking tasks, and that user reaching and target selection follow the basic parameters of Fitts Law. However, where few on-screen selections are available, or

where the use of a mouse would not work well (e.g., in a mobile application), touch screens with pre-defined tabbing zones have proven suitable, and there are claims of rapid input speeds with stylized input such as Graffiti (a simplified, single stroke script designed for writing in a natural pen-based manner with the well-known Palm Computing series of devices). The QWERTY keyboard remains dominant despite evidence that more optimal keyboard layouts could be designed, hinting at one important aspect of design that is beyond the control of science, the influence of precedent, habit and market forces.

4.3 Supporting accurate mental model formation

Contemporary work on HCI uses the concept of mental model extensively. The basic assumption is that users must try and understand what is happening with a system when they issue commands and since much of the activity is hidden, they have to rely on inference. Depending on their knowledge of computing or the task being performed, users may infer correctly or incorrectly, but each user develops their own image of the technology and how it works (though these may be broadly similar across many users).

HCI research suggests that designers should regard models as mental scaffolding upon which users hang their ideas about how the system works. The user's model is a personalised, often idiosyncratic view of what the system does and how it does it. The designer should seek to make important aspects of the design transparent, coherent and supportive. Another source of the users mental model is prior experience particularly with related products. If the user has worked with another system or an older version of the existing system then that is bound to influence their perception of the new technology since their existing schemata will all be brought to bear on their initial interactions. The users experience of performing the tasks is also a contributing factor in the development of their model, and designers are advised to exploit the language, mappings, relationships among concepts, and procedures used by the target audience in creating an interface.

4.4 Use of metaphors to enhance comprehension and learning

Another generic aspect of human cognition that seems readily exploitable by designers is the reliance of human thinking on metaphors and analogies. Linked to the general

tendency to model and to learn by analogy, the logic behind metaphors is that they enable users to draw on existing world knowledge to act on the new domain.

There has been much discussion within HCI of the merits of the metaphor approach in dialogue design, and it is argued that there are two relevant dimensions for understanding the information metaphors convey: *scope* and *level* of description. A metaphors scope refers to the number of concepts to which it relates. A metaphor of broad scope in the domain of HCI is the desk-top metaphor common to many computing interfaces. Here, many of the concepts a user deals with when working on the system can be easily dealt with cognitively in terms of physical desk-top manipulations. The metaphor of the World Wide Web as an information superhighway is similarly broad. The typewriter metaphor that was often invoked for explaining word processors is far more limited in scope. It offers a basic orientation to using word processors (i.e. you can use them to create print quality documents) but is severely limited beyond that as word processors do not behave like typewriters in many instances (e.g., typewriters do not save and store files, allow easy reformatting of text or make instant copies of documents).

The metaphors level of description refers to the type of knowledge they are intended to convey. This may be very high level information such as how to think about the task and its completion, or very low, such as how to think about particular command syntax in order to best remember it. Theorists in HCI talk of four levels: task, semantic, lexical and physical which refer to general issues such as: Can I do it?; What does this command do?; What does that term mean? and What activities are needed to achieve that? respectively.

Few, if any, metaphors convey information at all levels but this does not prevent them being useful to users. In fact, few users ever expect metaphors to offer full scope and levels of description so any metaphor employed should have its limitations and exceptions clearly pointed out. If the user cannot easily appreciate the metaphorical aspects and functional relations that are or are not essential to its use then the power of the metaphor will be greatly reduced. Of all the cognitive science concepts used in HCI, metaphor has proved one of the most durable and accepted.

4.5 Learning by doing

The most successful systems are those that enable a user to get something done as soon as possible. Users tend to be very resistant to reading any accompanying documentation and often want to get on with real tasks immediately rather than follow any training guides. In this sense, error-free performance is not considered a real goal. Instead, cognitive scientists emphasise the importance of clear and informative feedback, and the ability to undo actions as more important in supporting the user through the learning curve.

Having gained some knowledge by using one part of a system, users will expect to be able to apply this throughout the system. Particular attention should be paid to the consistent use of terms, colours and highlighting techniques, and the positioning of task related zones on the screen so as to support generalization by the user. Consistency can also be important to maintain between systems say the old and the new versions. The benefits of a new system can easily be obscured if users feel that their existing knowledge is now redundant and they must learn the new system from scratch.

4.6 Minimizing attentional and cognitive load

Theoretical insights into cognitive architecture emphasize the memory and attentional constraints of humans. These lessons have been learned by the HCI community who argue that interaction sequences should be designed to minimise short term memory load (e.g. not demanding a user choose from an excessive number of menu items; requiring the user to remember numbers or characters from one screen to another, etc.). Since recognition memory is superior to absolute recall, the use of menus is now the norm in design compared to the command line interfaces of the 1980s, which required users to memorise control arguments.

Similarly, a major contribution of cognitive science perspectives to user interface design has been in the area of task sequencing. User interface designers are encouraged to minimise the number of steps where information must be retained by the user. Instead, designers are encouraged to provide all necessary information in the interface for the user to exploit as needed. The use of animation is recommended only where a process is being explained, although many designers deliberately exploit the natural human perceptual

tendency to attend to movement by using animation to capture attention, particularly for advertisements in web-based commercial sites.

4.7 Using images and icons

Screen real-estate is a limited commodity and designers continually seek means of conveying concepts and actions through the language-independent medium of signs, images and symbols. A secondary push for more iconic interfaces is their presumed ability to cross cultural boundaries and enable international use.

Semiotic approaches to design have been invoked to help designers create appropriately comprehensible icons but the results have been mixed. Current interfaces make extensive use of graphic capabilities and iconic representations but couple these with pop-up text labels that explain meaning to users who find the representations difficult to decipher.

5. Beyond guidelines Cognitive theories and models in HCI

It is not yet possible to talk of a complete theory of human-computer interaction, given the many activities, processes, and tasks that computers support. However, to overcome the piecemeal approach that results from repeated empirical tests of evolving interface features, attempts have been made to produce stronger theoretical models to guide interface designers. This approach has worked best where it has been constrained to explain specific or localised interactive phenomena rather than the full range of user responses to information technology.

5.1 Interaction as Serial Information Processing

Cognitive scientists have derived many findings about human information processing, and this knowledge has been distilled in the area of HCI into a form of engineering model of the user that can be exploited by designers. Generally referred to as the model human processor, this cognitive model enables interface designers to predict the time a user will take to complete a task sequence given an analysis of the cognitive, perceptual and psychomotor components that are applied at each step. For example, to determine how long it would take a user to complete the task sequence involving saving a file to hard

disk, consider the following data points, derived from years of laboratory studies of humans to provide indices of various interactive acts:

Label	Action	Time estimate (seconds)
Tk	Enter a keystroke	0.23
Th	Move hands to mouse	0.36
Tp	Time to point	1.5
Tm	Retrieve from memory	1.2
Tr	Time for computer to respond	1.2

Table 1 Time estimates for completion of basic interactive tasks by a human operator

To apply such a model model, the evaluator would first compute the basic steps a user must take with an interface. We can imagine a proposed design that requires the user to locate the mouse (Th) move the mouse to a menu (Tp), select the save command (Tp), allow the system to respond with a prompt (Tr) input the filename (Tk x No.of letters) and then hit a save button (Tk). The designer could very quickly use the estimates from Table 1 to calculate how long a user would take to perform this sequence and use these data to determine trade-offs in the proposed design.

The exact value of the estimates can be argued over, but the principle of the model human processor is constant, i.e., decompose the task into its constituent actions and calculate the time involved in the serial processing of these acts. Multiple applications of this method have confirmed its value in estimating expert or error-free task completion times for repetitive, non-discretionary tasks.

Of course, this model has its limitations. We cannot use it to estimate how long users will spend on tasks that are not highly practiced, or that require decision making, planning, or learning. Similarly, where tasks involve parallel processing, it is easy to overestimate times by assuming simple serial processing of the task actions. However, as an applied

model of cognition for a constrained range of routine and well-practiced tasks, such a technique is clearly useful.

There have been several extensions of this approach, most notably to cover learning. Based on a production system analysis, (describing the behaviour a user must learn to complete a task in terms of a series IF-THEN rules of interactive sequences, e.g., IF file is "new" THEN select menu option "New File" etc.) Cognitive Complexity Theory enables calculation of the estimated time it would take a user to learn a new procedure. According to current findings, each new If-THEN rule production will take a typical user approximately 25 seconds to learn. Armed with such knowledge, designers could estimate, for example, the costs involved in changing procedures or violating consistency of interaction with new designs. This is obviously a gross estimate but for many proceduralised tasks, the data indicate the underlying regularity of human performance.

5.2 Socio-cogntive analyses of HCI: activity theory and acceptance models

An alternative application of cognitive theory has emerged as HCI researchers became interested in user acceptance of computers and the exploitation of technology by groups of users. Such research draws less on the classic experimental base of laboratory findings within cognitive science and more on its social and anthropological traditions. I have classified these together under the general heading of socio-cognitive theories.

Activity theory aims to bring a closer reading of cultural forces to bear on our analyses of interaction. Users are seen as situated within a context that exerts strong forces on their actions. Furthermore, such users are dynamic, changing as their experience and application of technology changes. Taking an activity theory perspective on HCI, it is important to extend analyses of interface usability to cover the context in which the technology is used (or rejected).

Typical activity theoretic approaches examine HCI in terms of the praxis, or situated context, e.g., a banking organization, a teaching scenario, or a medical process, in which the various levels of interaction can run from automatic individual operations to collective ventures or activities that define the groups purpose. The analysis and design of

any technology needs to be grounded in such a broader perspective to ensure it is appropriate and usable by the intended user community. In this way, one can see activity theory as extending traditional cognitive approaches rather than replacing them.

Other social-oriented approaches to HCI that consider cognition include the general class of acceptance theories that seek to predict if a user, given some choice, will utilise a technology. Such models emphasise the perceived value that users place on the new technology, and measure the relationship between such ratings and subsequent behaviour in context. For example, it is now known that if a user perceives a new tool as having direct usefulness for them in their work, they will be more likely to choose it, and may trade-off certain ease of use attributes for the power it affords them. Such perceptions by users seem to be formed very quickly, often within minutes of interacting for the first time, placing special emphasis on the value of early impressions due to aesthetics, implementation style and related factors.

Theoretical developments in HCI have not kept pace with developments in technology, partly because of the speed of technological change but, more likely, due to the difficulty of translating cognitive science into rich theoretical models that predict human behavior in multiple contexts. While there is an occasional dismissal of the theoretical approach as too limited for practical application, most HCI professionals are of the view that long-term progress is only possible with increased effort at deriving and applying cognitive science theories to the problems of user interface design.

6. Developing user-centered design methods

Where design guidelines and theoretical models of interaction fail to provide sufficient answers, design teams resort to usability tests of their user interfaces. Cognitive scientists have contributed to this effort by providing the methodological and analytical perspective that informs evaluation practice.

Within HCI there are three basic evaluation methods: expert-based, model-based and user-based. As indicated above, expert-based approaches assess an interface for compliance with known design principles and guidelines. As I have indicated, most of

these guidelines are the products of cognitive science oriented research. Model-based approaches fall directly from the models mentioned in the previous section. They are the application of theoretical models to specific design questions and are almost always applied by those who have received some training in cognitive science. Both of these approaches are seen as fast and relatively cost-effective, but they are known to be limited in what they can predict.

User-based approaches, as the name suggests, involve testing an interface with a sample of representative users in an appropriate context. There are as many variations on this theme as there are cognitive science methods of enquiry, ranging from controlled laboratory trials akin to psychology experiments, to field-based explorations derived from anthropological methods.

The pressures of design place demands on HCI professionals to produce fast answers and cognitive scientists have worked on problems of improving test method reliability and validity. Current emphases include deriving better expert-based evaluation methods to overcome the rather poor validity of such methods (testers employing these methods tend to overestimate the number of problems users actually experience, that is, they label as problems many aspects of interfaces that users subsequently perceive as acceptable). Similarly, effort has been spent trying to package formal methods into tools that can be used effectively by non-cognitive scientists to predict usability. The dream of this approach is that software tools could be developed which designers would use to calculate learning effort or time to perform a task, without the designer having to know the details of how such an estimate is derived. The analogy is frequently made to the use engineers can make of the principles of physics. To date, few such tools have made the transition from research laboratory to design practice.

7. Summary

User interface design has proved to be a complicated process that requires detailed analysis of human performance and preference. Furthermore, developments in technology require an understanding of the emotional and trust aspects of interaction that

have yet to be studied in detail by cognitive scientists. As a form of applied cognitive science, interface design is a fruitful testing ground for a range of cognitive theories and methods, and this is only the beginning. Further developments in the area of digital technologies will create ubiquitous computing devices that will surround us at work, in leisure and in our public and private lives. In such cases, cognitive scientists will be called on to aid the design and to study the impact of such technologies routinely, and theory will meet practice in a manner that is likely to be hugely important for our future well-being.

Bibliography

Card, S., Moran, T. and Newell, A. (1983) The Psychology of Human-Computer Interaction. LEA.

Landauer, T. (1995) The Trouble with Computers. Cambridge MA: MIT Press

Norman, D. (1986) The Design of Everyday Things. New York: Basic Books

Helander, M., Landauer, T., and Prabhu, P. (eds) (1997) Handbook of Human-Computer Interaction, Amsterdam: Elsevier

Rosson, M. and Carroll, J. (2001) Usability Engineering. San Francisco: Morgan-Kaufmann

Glossary

User interface design

Human Computer Interaction

Applied Cognitive Science

Definitions

Human-Computer Interaction: the field of study concerned with the design and implementation of humanly usable and socially acceptable information technologies

Usability: the effectiveness, efficiency and satisfaction with which specific users can perform given tasks in a particular environment with a software application.

Word Processor Used- MS Word 98 for Macintosh